# FABRICATION OF A PHYSICS PROTOTYPE DTL & LASER WELDING TRIALS FOR COPPER DRIFT TUBES

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*Abstract*

The detailed physics design of the Drift Tube Linac (DTL) for the 20 MeV, 30 mA, Low Energy High Intensity Proton Accelerator (LEHIPA) [1] has been completed. To validate the design, a 1.2 m long physics prototype was built. In this paper we present engineering details of the prototype, including machining and inspection of the tank and drift-tubes. Further, we have initiated trials to explore the possibility of laser-welding of the DTs. We present details of the issues involved in laser welding, and results of the trials.

## INTRODUCTION

The DTL, resonating at a frequency of 352.21 MHz, has been designed to accelerate the proton beam from 3 to 20 MeV. The total length of the DTL is 12.86 m, but for ease of fabrication it will be built in eight tanks, each of length about 1.51 m. As a first step, a 1.2 m long prototype was manufactured to assess manufacturing challenges associated with the DTL and to validate its RF characteristics. Although it was possible to carry out physics experiments on a shorter prototype, a longer tank was necessary to assess the difficulty in maintaining machining accuracies over longer lengths. RF tests were conducted in air on this prototype [2]. Outcomes of prototyping are discussed in the next section.

We have also initiated trials to establish the parameters of metal-joining techniques. Laser welding is presently preferred over other metal-joining techniques. However, laser welding of copper is challenging due to its high laser-reflectivity and high thermal-conductivity. To counter these issues, during welding, lip type joint design was used, and oxygen was mixed with argon as cover gas. Results of trials are discussed in section 3.

## PHYSICS PROTOTYPE

We have manufactured a 1.2 m long prototype, containing 16 full-DTs, 2 half-DTs, 3 tuner ports, 2 RF ports, and 1 vacuum port (Fig. 1). All the parts of prototype that get exposed to RF power have geometries identical to the final DTL. The DTs for the prototype (Fig. 2) were fabricated without any internal features like permanent quadrupole magnets and cooling circuits, as would be needed in the real DTL. Cooling system for the tank and other components such as post-couplers were also not incorporated in the prototype.

### *Fabrication Details*

The designed DTL tank ID was 526 mm. It was machined from carbon steel (confirming to ASTM A-106, grade-B) pipe of OD 610 mm and ID 520 mm. ID of the tank was copper electroplated to improve electrical conductivity of its internal surface. To facilitate RF tests, 2 RF ports, and 3 tuner ports – with thread on their IDs – were welded to the tank. Three tuners were also fabricated. These were solid aluminum cylinders with threads on their OD. With the help of these threads the tuners can be moved in the radial direction of the tank. RF ports are covered with help of the RF closures. These closures have an arrangement to fit N-type connectors on them, for making the RF measurements. Half DTs were mounted on the cover plate. One mild steel mandrel was also used for rough alignment of the DTs.

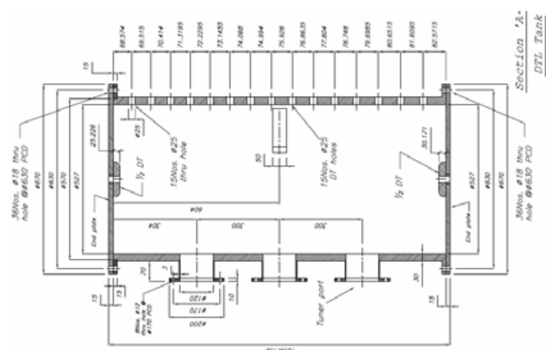

Figure 1: Cross-sectional drawing of DTL prototype.

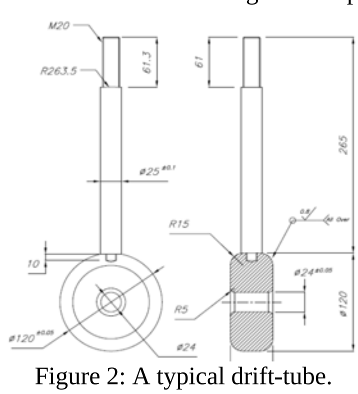

Figure 2: A typical drift-tube.

### *Mechanical Inspection*

Diameter of the DT-holes on the DTL tank and their locations were critical for DT alignment. Most of them met position tolerance of ±125 µm. Tank could be machined within ±50 µm of its nominal length. Drift tube OD and ID could be maintained within ±20 µm and ±50 µm respectively. Effects of tool wearing and overhanging tool were seen on the diameter of the tank. Average ID of the tank on one end is 527.1 mm and on the other end it is

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526.6 mm. Plating of approximately 50 μm was done on the inside surfaces of the tank and on the cover plate. It was found satisfactory for low power physics tests. However, quality of plating should be improved for high power applications.

### *Results of RF Tests*

Detailed RF tests were conducted on the prototype [2]. RF resonant frequency was measured to be 349.49 MHz as opposed to designed frequency 351.67 MHz. This difference can be corrected by reducing DTL tank ID by 4.45 mm or the drift tube OD by 2.53 mm.

## LASER WELDING TRIALS

The drift-tubes of the DTL will be made of OFE copper. Permanent focusing magnets will be housed inside the DTs. Total 3 nos. of vacuum-tight metal joints with high quality surface finish (0.8 μm CLA) are to be made on each drift tube. Two of them are to be made after placing the magnets inside the DT structure. Due to temperature sensitivity of permanent magnets, these joints cannot be made by TIG (Tungsten Inert Gas) welding. Electron beam welding will also be challenging due to the influence of magnetic fields on the electron beam. In view of this, laser welding seems to be best option available. However, high laser reflectivity and thermal conductivity of copper makes its laser welding a difficult proposition. Trials were initiated at RRCAT, Indore, to assess the viability of laser welding. An Nd:YAG, pulsed laser, of wavelength 1064 nm, with peak power of 7 kW and average power of 500 W was used for trials.

### *Procedure*

In the first round of trials, linear, butt joints were welded on the OFE copper plates with thickness ranging from 0.5 mm to 1 mm. Argon was used as cover gas. Welded joints had poor strength and depressions on the joints were found.

A second round of trials was initiated to optimize various parameters. This time argon-oxygen cover gas was used during welding to increase welding depth and strength of the joint. Formation of copper oxide helps in enhancing the absorption of the laser at the copper surface. This in turn increases heat deposition, which results in higher penetration. However, the presence of oxygen increases porosity in the weld bead, and therefore only 5-10% of oxygen was supplied.

Under these conditions, 1 mm thick OFE copper plates were first welded. Welding parameters that gave the best results were then used to weld two smaller size models of DTs. Each DT model had two circular joints (Fig. 3). Projections of 0.3 mm height and 0.2 mm thickness were machined on the joint to reduce heat conduction from the joint and to reduce depression in the weld bead. In the welding pass, best results were achieved with the following laser parameters: spot size 0.7 mm, 4 Hz frequency, and pulse duration 10 ms. Cosmetic pass was also taken to improve surface finish of the joint.

### *Results*

Linear joints showed helium leak rate $<10^{-10}$ std cc/sec. Circular joints in DT model had helium leak rate $<10^{-8}$ std cc/sec. Difference in leak-tightness between linear and circular joint results can be attributed to mechanisms that were used to move the job with respect to static welding head. In case of linear joints, feed rate could be precisely controlled with help of CNC mechanism. In case of circular joints, such mechanism was not available readily.

Figure 3: Laser-welded OFE copper samples.

All the specimens show depressions (undercuts) in the weld beads. We plan to increase the height of the lip to counter this effect. Tensile tests were also conducted. Following are the main results of the tests: a) welded joint has strength around 60% of the parent material; b) ductility is reduced. Following table lists results of tests.

Table 1: Results of tensile tests.

| Sample No. | Yield Strength | Ultimate Strength | Cross-section Reduction (%) |
|---|---|---|---|
| 1 | 126 MPa | 172 MPa | 19 |
| 2 | 112 MPa | 176 MPa | 24 |
| 3 | 135 MPa | 188 MPa | 27 |
| 4 | 148 MPa | 202 MPa | 28 |

## CONCLUSION

Prototyping was useful in understanding manufacturing issues associated with DTL. All components could be machined to within the specified tolerances, due to which the RF measurements on the prototype were also in good agreement with simulations. However, quality of plating will have to be improved for the actual DTL. Issues related to cooling and vacuum-sealing have not been addressed, for which we plan now to develop a full engineering prototype. Laser welding trials on OFE copper showed that it is a viable option. Vacuum tight joint could be made. However, further trials are needed to get better surface finish.


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## REFERENCES


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